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The anatomy and histology of the bicipital tunnel of the shoulder

Samuel A. Taylor, MD[a,*], Peter D. Fabricant, MD, MPH[a], Manjula Bansal, MD[b], M. Michael Khair, MD[a], Alexander McLawhorn, MD, MBA[a], Edward F. DiCarlo, MD[b], Mary Shorey, BA[a], Stephen J. O'Brien, MD, MBA[a]

[a]*Sports Medicine and Shoulder Service, Hospital for Special Surgery, New York, NY, USA*
[b]*Pathology and Laboratory Medicine, Hospital for Special Surgery, New York, NY, USA*

Background: The bicipital tunnel is the extra-articular, fibro-osseous structure that encloses the long head of the biceps tendon.
Methods: Twelve cadaveric shoulder specimens underwent in situ casting of the bicipital tunnel with methyl methacrylate cement to demonstrate structural competence (n = 6) and en bloc harvest with gross and histologic evaluation (n = 6). The percentage of empty tunnel was calculated histologically by subtracting the proportion of cross-sectional area of the long head of the biceps tendon from that of the bicipital tunnel for each zone.
Results: Cement casting demonstrated that the bicipital tunnel was a closed space. Zone 1 extended from the articular margin to the distal margin of the subscapularis tendon. Zone 2 extended from the distal margin of the subscapularis tendon to the proximal margin of the pectoralis major tendon. Zone 3 was the subpectoral region. Zones 1 and 2 were both enclosed by a dense connective tissue sheath and demonstrated the presence of synovium. Zone 3 had significantly greater percentage of empty tunnel than zones 1 and 2 did ($P < .01$).
Conclusion: The bicipital tunnel is a closed space with 3 distinct zones. Zones 1 and 2 have similar features, including the presence of synovium, but differ from zone 3. A significant bottleneck occurs between zone 2 and zone 3, most likely at the proximal margin of the pectoralis major tendon. The bicipital tunnel is a closed space where space-occupying lesions may produce a bicipital tunnel syndrome. Careful consideration should be given to surgical techniques that decompress both zones 1 and 2 of the bicipital tunnel.
Level of evidence: Basic Science, Anatomy/Histology.

Keywords: Long head; biceps tendon; bicipital tunnel; biceps tendinitis; tenodesis

Whereas intra-articular delivery of the long head of the biceps tendon (LHBT) during glenohumeral arthroscopy with a probe is considered the "gold standard" diagnostic modality,[1] recent studies showed that this offers a limited evaluation of the biceps-labral complex.[8,20] Furthermore, in their large clinical series, Taylor et al[20] identified a hidden extra-articular lesion affecting the LHBT in 47% of chronically symptomatic patients (Fig. 1). They defined the bicipital tunnel as the extra-articular fibro-osseous confinement of the LHBT that extends from the articular margin through the subpectoral region.

IRB: This study was approved by the IRB at Hospital for Special Surgery, New York, NY (IRB #13200).

*Reprint requests: Samuel A. Taylor, MD, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, USA.
E-mail address: samueltaylor.md@gmail.com (S.A. Taylor).

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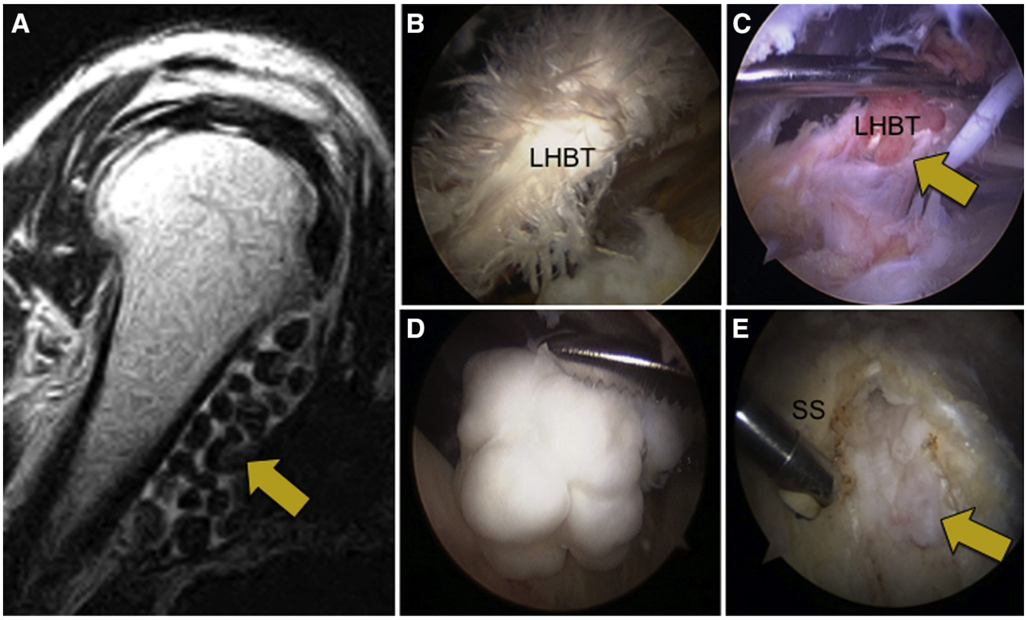

Figure 1 The extra-articular bicipital tunnel is a closed space in which lesions such as loose bodies can aggregate (**A**, *arrow*) as seen on this sagittal view magnetic resonance image. Several different space-occupying extra-articular lesions have been identified within the bicipital tunnel at the time of transfer of the long head of the biceps tendon (*LHBT*) to the conjoint tendon in symptomatic patients that would not have been visualized arthroscopically, including partial tears (**B**), adhesion and scar formation (**C**, *arrow*), loose bodies (**D**), and osteophyte formation (**E**, *arrow*). *SS*, subscapularis.

This discovery of the bicipital tunnel becomes clearly clinically relevant in considering data from a systematic review that indicate persistent biceps symptoms in nearly 25% of patients after tenodesis or tenotomy.[19] It is our experience that the extra-articular LHBT is consistently contained by a soft tissue sheath in all patients to the proximal margin of the pectoralis major tendon (PMPM), creating a tunnel within which space-occupying lesions can aggregate. Sanders et al[18] explored the role of the bicipital sheath on tenodesis outcomes by stratifying results by surgical technique. They demonstrated a significantly higher failure rate (20.6% vs. 6.8%) for procedures that did not release the extra-articular bicipital sheath compared with those that did.

Defined herein is the anatomy and histology of this clinically essential structure called the bicipital tunnel, which we have divided into 3 distinct anatomic zones (Fig. 2). Zone 1 represents the traditional bony bicipital groove and extends from the articular margin (defined by the confluent fibers of the biceps pulley) to the distal margin of the subscapularis tendon (DMSS). The majority (78%) of the LHBT within zone 1 can be visualized during standard diagnostic arthroscopy.[20] Zone 2 extends from the DMSS to the PMPM and represents a ‘‘no man’s land’’ because it remains entirely hidden from arthroscopic view above[20] and from open subpectoral exposure below. Zone 3 is the subpectoral region.

The purpose of this study was to define the 3-dimensional anatomy and histology of the bicipital tunnel. Such information would advance the collective understanding of the pathogenesis of ‘‘biceps tendinitis,’’ explore why some biceps procedures are unsuccessful, and guide surgical technique. On the basis of our previous clinical experience, we hypothesized that (1) the bicipital tunnel is a closed space, (2) it consists of 3 distinct anatomic and histologic zones, and (3) a functional bottleneck exists between zones 2 and 3.

Materials and methods

Fifteen adult human fresh frozen cadaveric specimens (mid-clavicle to fingertips) were considered for evaluation. No surgical scars, evidence of prior trauma, or gross deformities were evident before arthroscopic examination. Passive glenohumeral and elbow ranges of motion were full for all specimens. Three specimens were disqualified after diagnostic arthroscopy because of preexisting disease (subscapularis tear, n = 1; high-grade partial tear of the LHBT, n = 1; complete LHBT rupture in the setting of supraspinatus tear, n = 1). The remaining 12 specimens were divided randomly into 2 groups: 6 specimens would undergo cement casting of the bicipital tunnel, and 6 specimens would undergo en bloc resection of the bicipital tunnel and histologic evaluation to test our 3 hypotheses.

Hypothesis 1: the bicipital tunnel is a closed space

Six cadaveric human, fresh frozen, upper extremity specimens (3 male and 3 female) underwent cement casting of the bicipital tunnel. The average age of these specimens was 65.2 years (range, 45-81 years). Each specimen underwent arthroscopic release of the LHBT from its intra-articular origin. A standard posterior

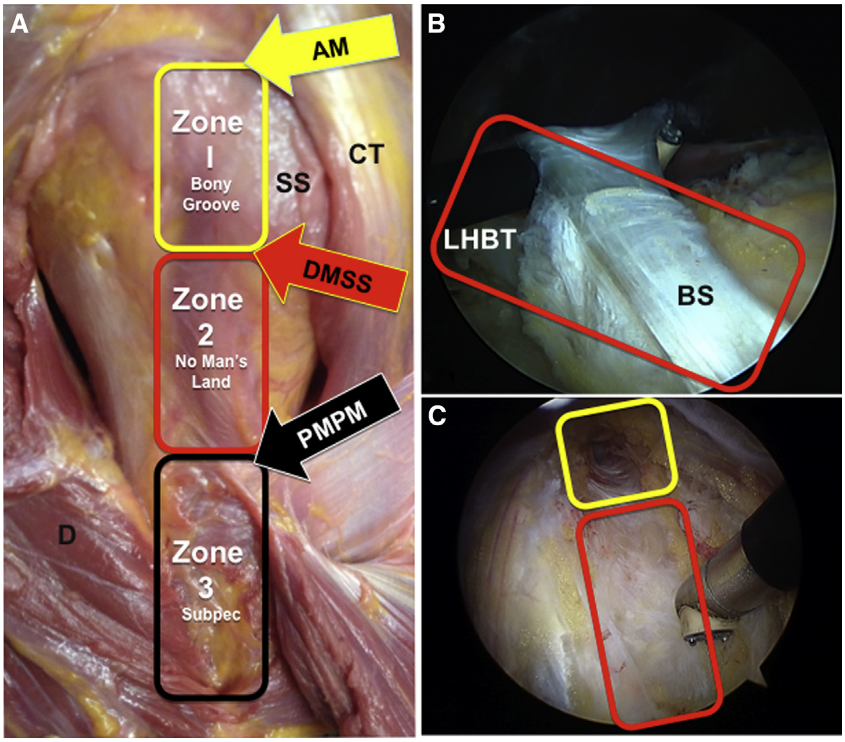

Figure 2 A soft tissue sheath (**A** and **B**) consistently covers the long head of the biceps tendon (*LHBT*) to the level of the proximal margin of the pectoralis major tendon (*PMPM*) and contributes to the roof of the bicipital tunnel. The sheath is clearly visible during open procedures (**A**) and extra-articular arthroscopic procedures within the subdeltoid space (**B** and **C**). The fibro-osseous bicipital tunnel consists of 3 distinct anatomic zones (**A**). Zone 1 represents the traditional bony bicipital groove (*yellow box*) beginning at the articular margin (*AM*) and ending at the distal margin of the subscapularis tendon (*DMSS*). Zone 2 (*red box*) extends from the DMSS to the PMPM and represents a "no man's land" because it is not viewable from arthroscopy above or from subpectoral exposure below. Zone 3 is distal to the PMPM and represents the subpectoral region. The sheath overlying zone 2 can be robust (**B**). *D*, deltoid; *SS*, subscapularis; *CT*, conjoint tendon; *BS*, bicipital sheath.

portal was used for viewing, and a standard anterior rotator interval portal was used to release the tendon. The anterior portal was established under spinal needle localization to prevent iatrogenic damage to the subscapularis tendon.

Open exposure was then performed through an extended deltopectoral interval. The glenohumeral joint was opened by releasing the infraspinatus and posterior portion of the tendinous insertion of the supraspinatus along the greater tuberosity. The biceps pulley was not interrupted. Exposure extended distally to the inferior margin of the pectoralis major.

Methyl methacrylate bone cement (Simplex; Stryker, Kalamazoo, MI, USA) in its early viscous, liquid state was injected into the bicipital tunnel in an anterograde direction with a 60-mL piston syringe under constant manual pressure to elucidate the 3-dimensional architecture and structural competence of the bicipital tunnel. It was allowed to freely extrude from the tunnel distally. After the cement hardened, the overlying soft tissues of the bicipital tunnel were removed and examined grossly for quality. The cement cast was marked at the articular margin, DMSS, and PMPM locations.

Hypothesis 2: the bicipital tunnel has 3 distinct anatomic and histologic zones

Six cadaveric human, fresh frozen, upper extremity specimens (4 male, 2 female) underwent en bloc resection of the bicipital tunnel and histologic examination. The average age of these specimens was 59.9 years (range, 23-76 years).

The LHBT was locked into a static position within the bicipital tunnel while the upper extremity was maintained in a resting position (shoulder neutral, elbow flexed to 90°, and neutral forearm rotation) by suture fixation proximally at the articular margin and distally at the distal margin of the pectoralis major tendon to prevent tendon motion during en bloc harvesting and subsequent tissue processing. A scalpel was used to sharply incise the soft tissues to bone over a 90° arc centered on the bicipital tunnel, enabling preservation of its constraining soft tissues. An oscillating saw was then used to cut a 90° arc of the humeral circumference to include the entire bicipital tunnel.

The resulting specimen was then photographed and fixed in 10% buffered formalin for 48 hours. The specimens were then frozen at −80°C for 48 hours to facilitate sectioning with a band saw. A representative 5-mm-thick axial block was cut from each of the midportions of zone 1 and zone 2. The zone 3 block was harvested from a point 1 cm distal to the PMPM. Radiographs were taken of the blocks from each zone to define osseous architecture. They were subsequently decalcified, embedded in paraffin, cut into 4-μm-thick axial sections, stained with hematoxylin and eosin and Masson trichrome stains, and evaluated with light microscopy by 2 board-certified pathologists who were blinded to the zone of origin.

Hypothesis 3: a functional bottleneck occurs between zone 2 and zone 3

The percentage of empty tunnel (%ET) was calculated histologically by subtracting the proportion of cross-sectional area of tendon from the overall cross-sectional area of the bicipital tunnel in each zone. Cross-sectional areas of the biceps tendon and the bicipital tunnel were measured from digitized histology slides with Adobe Photoshop CS6 Extended software (Adobe Systems, Inc., San Jose, CA, USA). The measurement scale for the software was calibrated with a 2-mm marker. The Magnetic Lasso Tool was then used to select the areas of interest: the biceps tendon itself as well as the constraining fibro-osseous bicipital tunnel. The cross-sectional area of the biceps tendon was defined by the area of eosin-stained, dense collagen fibers, and the cross-sectional area of the bicipital tunnel was defined by the inner boundary of the constraining soft tissues. The software then measured and recorded each calibrated area. Data from the software's Measurement Log were exported into a comma-delimited data file where %ET was calculated for each zone by subtracting the proportion of cross-sectional area of LHBT from that of the bicipital tunnel.

A member of the research team with advanced training in biostatistics performed the statistical analyses with SAS software version 9.3 (SAS Institute, Inc., Cary, NC, USA). Descriptive statistics were used to evaluate the distribution of continuous data. The %ET in each zone along the length of the biceps tendon was assessed for normality and evaluated with a mixed-models repeated measures analysis. This allowed comparisons that take into account both "within-specimen" and "between-specimen" variation. Post hoc pairwise comparisons between zones were performed with Tukey-adjusted P values. All analyses that generated P values were two tailed and used $P = .05$ as the threshold for statistical significance.

Results

Result 1: the bicipital tunnel is a closed space

Cement casting demonstrated the bicipital tunnel to be a closed space from the articular margin to a minimum of 3 cm distal to the PMPM in all specimens (Fig. 3, *A*). The constraining soft tissues were of variable thickness in zone 2 but substantive enough to prevent liquid cement extrusion in all specimens (Fig. 3, *B* and *C*).

Result 2: the bicipital tunnel has 3 distinct anatomic and histologic zones

Histologic evaluation of axial sections taken from the bicipital tunnel demonstrated 3 distinct anatomic and histologic zones (Table I). Zone 1 was consistently marked by synovium that circumferentially enveloped the LHBT, a deep osseous groove, and a thick fibrous roof consisting of fibers from the subscapularis tendon (Fig. 4, *A*). In Zone 2, 67% of specimens demonstrated the presence of synovium, and all had a shallow osseous trough along with proximal extension of latissimus dorsi fibers (Fig. 4, *B*). The roof of the tunnel in zone 2 consisted of axially oriented dense connective tissue fibers of the sheath, which surrounded the LHBT circumferentially and connected directly to bone laterally, and longitudinally oriented fibers of the falciform ligament. Zone 3 had a flat osseous floor covered with latissimus dorsi fibers (Fig. 4, *C*). The pectoralis major tendon formed the roof and inserted lateral to the LHBT on the humerus. Medially, the bicipital tunnel was constrained by either loose connective tissue (67%) or a thin veil of dense connective tissue (33%).

The falciform ligament was identified grossly as a proximal expansion of the sternocostal head of the pectoralis major fascia in all specimens. Its longitudinally oriented fibers blended with but were superficial to and distinct from the axially oriented fibers of the bicipital sheath. Falciform ligament fibers were identified in zone 2 in all specimens and extended into zone 1 in 33% of specimens.

The roof of the bicipital tunnel was thickest within zone 1 but was characterized by dense connective tissue in all specimens in both zones 1 and 2. In zone 2, the axially oriented dense connective tissue inserted directly to bone laterally.

The synovium enveloped the LHBT in zone 1 for all specimens. Synovium was identified in the majority of specimens (67%) in zone 2 and was seen rarely (18%) in zone 3.

Result 3: a functional bottleneck occurs between zone 2 and zone 3

The mean %ET of zones 1, 2, and 3 were 42.2%, 51.0%, and 66.0%, respectively. There was a significant overall association between zone and %ET (mixed-models repeated measures analysis, $P = .0003$), with %ET increasing with more distal histologic sections. Tukey-adjusted pairwise comparisons indicated that zone 3 had significantly more percentage empty volume than zones 1 and 2 ($P < .01$ for each). There was no significant difference in empty space between zones 1 and 2 ($P = .10$) (Fig. 5). This indicates a functional bottleneck, which occurs between zone 2 and zone 3.

Discussion

This study suggests a paradigm shift in the approach to the LHBT, the extra-articular bicipital tunnel, and the pathogenesis of biceps tendinitis. Our results demonstrate 3 novel, clinically relevant findings:

1. The bicipital tunnel is a closed space.
2. The bicipital tunnel has 3 distinct zones, but zones 1 and 2 share similar histologic features, including synovium, and differ significantly from zone 3.
3. A functional bottleneck occurs between zone 2 and zone 3 (likely at the PMPM) as demonstrated by statistically significant difference in %ET.

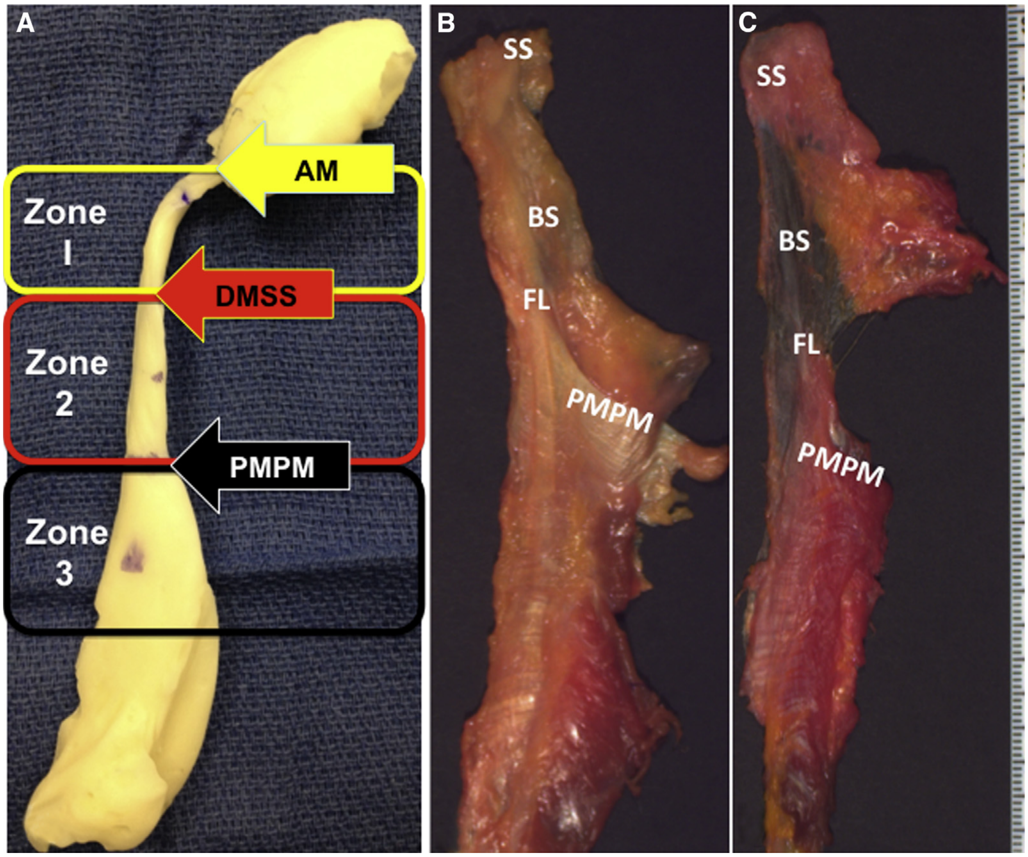

Figure 3 Cement casting (**A**) of the bicipital tunnel proved it to be a closed space in all specimens. After cement casting, the soft tissue roof of the bicipital tunnel was resected (**B** and **C**). Whereas the quality of this constraining soft tissue was highly variable among specimens, ranging from robust (**B**) to gossamer (**C**), it was structurally competent and contained the cement in all specimens. *AM*, articular margin; *DMSS*, distal margin of subscapularis tendon; *PMPM*, proximal margin of pectoralis major tendon; *FL*, falciform ligament; *BS*, bicipital sheath; *SS*, subscapularis.

Traditional teaching would suggest that lesions affecting the LHBT are predominantly proximal and result from mechanical abrasion[3,4,17] in the setting of a vascular watershed.[7,11] Despite this theory, a systematic review[19] reported only 74% good to excellent results for tenodesis patients and rates of persistent biceps symptoms approaching 25%. Given this information, one must ask the obvious question: Are we addressing the offending pathologic process?

Taylor et al[20] looked specifically at the extra-articular bicipital tunnel and determined that 47% of chronically symptomatic patients had hidden extra-articular lesions, including scar/adhesion, LHBT instability, stenosis, abrasive osteophyte, LHBT partial tearing, and loose bodies. Furthermore, 45% of patients with an intra-articular LHBT lesion *also had a hidden tunnel lesion*. Therefore, it is possible that proximal tenodesis techniques may leave concomitant bicipital tunnel lesions unaddressed. In fact, this concept was corroborated by Sanders et al,[18] who stratified revision rates by surgical technique in a cohort of 127 patients who underwent various biceps procedures. They found a statistically higher revision rate among techniques that left the bicipital sheath intact (20.6%) compared with techniques that released the sheath (6.8%). An improved understanding of the extra-articular bicipital tunnel is of paramount importance.

We used methyl methacrylate cement casting to demonstrate that the bicipital tunnel is a closed space. This was confirmed histologically by the axially oriented dense connective tissue sheath and longitudinally oriented fibers of the falciform ligament, which enclosed all specimens. This closed space concept is clinically relevant, given recent reports of hidden space-occupying lesions (scar, synovitis, loose bodies, and osteophytes) that were identified within zone 1 and zone 2[20] and may aggregate at the functional bottleneck between zone 2 and zone 3, most likely caused by mechanical compression of the pectoralis major tendon.

Diagnostic arthroscopy fails to fully evaluate the biceps-labral complex.[8,20] In particular, zone 2 represents a ‘‘no man's land'' because it remains hidden from arthroscopic view above and open subpectoral view below. Whereas some authors have begun to recognize the clinical relevance of the extra-articular bicipital tunnel,[9,13,20] the literature has overwhelmingly neglected zone 2 lesions in favor of more proximal disease, which is more readily visualized arthroscopically.[6,15,16]

Table I Summary of histologic findings organized by bicipital tunnel zone

Zone	Floor	Peritendinous	Roof	Comments
1	Deep osseous groove morphology (6 of 6) Continuation of subscapularis tendon fibers and periosteum (6 of 6)	Enveloped by synovium (6 of 6)	Continuation of fibers from the subscapularis tendon that blend with supraspinatus fibers laterally (6 of 6) Meshing of longitudinally oriented fibers of the falciform ligament (2 of 6)	Artery and 2 veins run parallel and lateral to LHBT within bicipital tunnel (5 of 6) Cystic osseous degeneration and osteophytes (2 of 6)
2	Shallow osseous trough (6 of 6) Circumferential bicipital sheath fibers most superficial (6 of 6) Loose areolar connective tissue interposed between bicipital sheath and periosteum (6 of 6) Distal expansion of subscapularis fibers (2 of 6) Proximal expansion of latissimus dorsi fibers overlies periosteum (4 of 6)	Partial extension of synovium with variable tethering to the overlying sheath and floor (4 of 6)	Axially oriented dense connective tissue bicipital sheath that continues circumferentially (6 of 6) Lateral extension of bicipital sheath fibers to the lateral aspect of the osseous floor (4 of 6) Falciform ligament identified as a discrete bundle of longitudinally oriented dense connective tissue (6 of 6) Variable course of the falciform ligament ranging from medial (2 of 6) to lateral (2 of 6) and broad and investing (2 of 6)	Artery and vein run in parallel with the LHBT both medial and lateral (4 of 6) Small osseous cysts without osteophyte formation (2 of 6)
3	Flat osseous base (5 of 6) Latissimus dorsi tendon overlies periosteum (6 of 6) Loose areolar connective tissue surrounds the LHBT (5 of 6)	Partial extension of synovium (1 of 6) Medial enclosure of loose connective tissue only (4 of 6)	Pectoralis major tendon (6 of 6)	Intrasubstance LHBT degeneration (2 of 6) Osseous cyst with small osteophyte (1 of 6)

LHBT, long head of the biceps tendon.
Parentheses indicate the number of specimens in which the finding occurred relative to the total number of specimens.

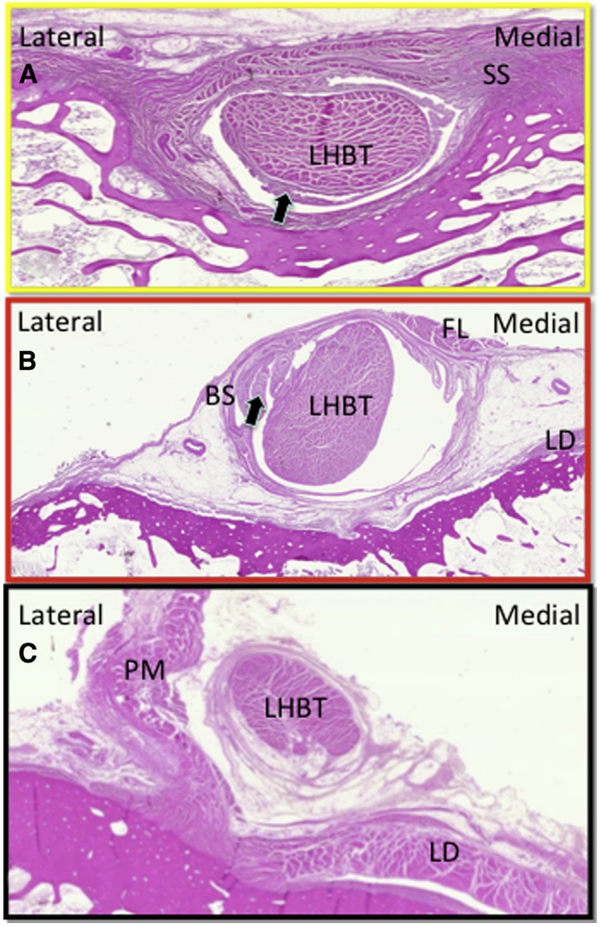

Figure 4 Hematoxylin and eosin staining of sections taken from each of the 3 anatomic zones of the bicipital tunnel. Zone 1 (**A**) shows continuation of the subscapularis (*SS*) fibers superficial and deep to the long head of the biceps tendon (*LHBT*), which blend with fibers of the supraspinatus laterally. Synovium (*arrow*) completely envelops the LHBT. Zone 2 (**B**) demonstrates the axially oriented circumferential fiber of the bicipital sheath (*BS*), which extended laterally to bone. The falciform ligament (*FL*) can be seen as a discrete superficial bundle of longitudinally oriented fibers along the medial aspect of the bicipital tunnel. Partial synovial extension is seen (*arrow*). Proximal extension of latissimus dorsi (*LD*) fibers is also seen in a subset of specimens. Zone 3 (**C**) shows thick fibers of the LD along the floor with a roof of pectoralis major tendon (*PM*). Medially, loose areolar connective tissue predominated.

A unique finding of the current study was the presence of synovium into zone 2 in 67% of specimens and even into zone 3 in 1 specimen (18%). To our knowledge, this is the first study to report synovium distal to the intertubercular sulcus. Synovitis may explain pain and ultimately could lead to adhesion and scar formation in zone 2, which was the most commonly identified lesion identified by Taylor et al.[20]

Gilcreest[6] described the intertubercular sulcus as an ‘‘osteofibrous tunnel of the bicipital canal.’’ Post and Benca[16] reported that the osseous groove ‘‘overlying transverse humeral ligament’’ formed a constraining tunnel. These authors astutely point out that lesions occurring within the bicipital groove (zone 1) may become symptomatic because of the tight nature of the close space. Our findings show that these same principles should be extended to zone 2.

Space-occupying lesions within the bicipital tunnel produce a ‘‘bicipital tunnel syndrome’’ and have ramifications on surgical technique. Our findings suggest that preference should be given to techniques that effectively decompress the bicipital tunnel, such as soft tissue tenodesis to the conjoint tendon,[5] open subpectoral tenodesis,[12] and suprapectoral tenodesis techniques that release the sheath.[10] On the basis of our %ET findings, decompression of the bicipital tunnel should include both zones 1 and 2, with release of the fibrous sheath to the level of the PMPM. One should apply caution if selecting a proximal tenodesis technique that leaves the sheath intact.

This study has limitations. Methyl methacrylate cement was introduced into the bicipital tunnel manually and without a pressure-monitoring device. The difference in viscosity between cement and synovial fluid may limit the generalizability of our findings. In addition, the tensile properties of the tunnel's soft tissue constraints were not investigated. The tunnel's diameter is likely a function of these two uncontrolled variables. Whereas future experiments should investigate the roles of the aforementioned limitations, this initial phase of the experiment did, however, serve to prove a novel concept—that the bicipital tunnel is in fact a closed space for all specimens from the articular margin to 3 cm below the PMPM. In an attempt to mitigate this limitation, we determined the %ET for each zone with histologic cross-sectional samples rather than with the cement casts. This methodology and subsequent analysis had several advantages. First, it provided a normalized percentage of free space within the tunnel, thus accounting for interspecimen variability rather than relying on absolute values that may vary according to the overall size of the specimen. Second, because each zone's %ET is not an independent measurement (e.g., it is influenced by the overall size of the specimen and %ET in other zones within the same specimen), another strength of the study was the use of a mixed-models repeated measures analysis with post hoc pairwise comparisons to determine if the %ET differed between zones. This analysis accounts for between-specimen and within-specimen variation rather than falsely assuming independence of measurements, thus allowing the isolation of %ET as the sole dependent quantitative variable.

Another limitation was that our static model did not account for the dynamic nature of the LHBT at the bicipital tunnel during en bloc harvest or muscle tone during cement casting. Normal glenohumeral motion produces 25 mm of LHBT excursion.[2,14] To capture the LHBT within the bicipital tunnel for histologic sectioning, it was necessary to fix the tendon to the soft tissues at the proximal and distal margins of the bicipital tunnel. We standardized the arm in a neutral position during LHBT capture within the bicipital tunnel.

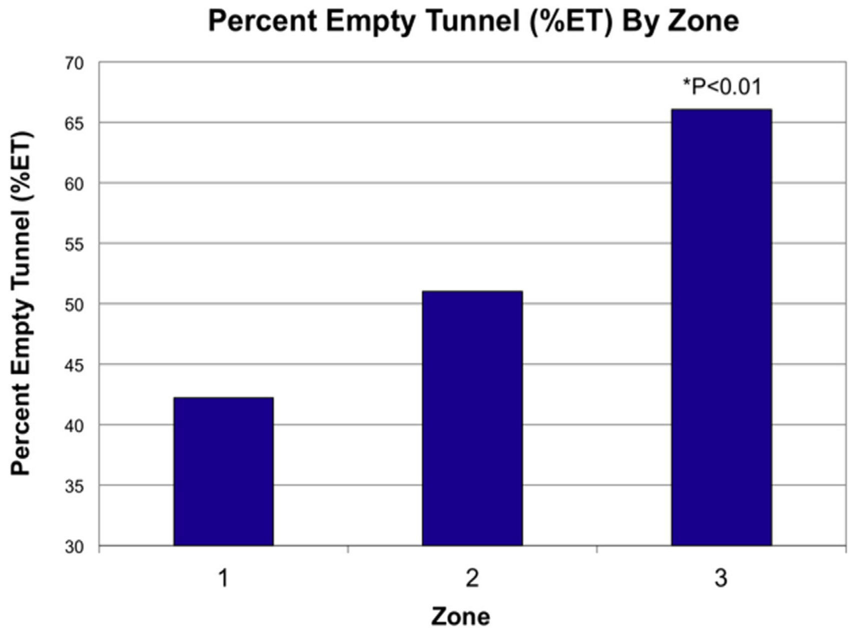

Figure 5 Percentage of empty tunnel (%ET) was significantly greater moving down the biceps tendon distally (mixed-models repeated measures analysis, $P = .0003$). Tukey-adjusted pairwise comparisons indicated that zone 3 had significantly more percentage empty volume than zones 1 and 2 ($P < .01$). There was no significant difference between empty space in zones 1 and 2 ($P = .10$).

Finally, the location of each block selected for histologic evaluation was from the approximate anatomic midportion of zone 1 and zone 2 and from 1 cm distal to the PMPM for zone 3. As such, we are unable to identify the exact bottleneck with regard to %ET, but just that it occurs between the selected region of zone 2 and zone 3. Thin sections through this junction would strengthen our study. Additional studies are under way to address these limitations.

Conclusion

This is the first description of the bicipital tunnel, which is a closed space with 3 anatomically and histologically distinct zones. Zones 1 and 2 were similar with regard to fibro-osseous structure, the presence of synovium, and reduced %ET but were distinct from zone 3. Space-occupying lesions, such as LHBT inflammation, LHBT partial tearing, loose bodies, scarring, and osteophytes within zone 1 and zone 2, may produce a bicipital tunnel syndrome. Careful consideration should be given to surgical techniques that decompress the bicipital tunnel, such as LHBT transfer to the conjoint tendon, open subpectoral biceps tenodesis, and proximal tenodesis that releases the constraining sheath.

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Disclaimer

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